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(19)

(54) IMPROVEMENTS IN OR RELATING TO SUPERCONDUCTING POWER SUPPLIES

(71) We, SCIENCE RESEARCH COUNCIL, London, a British Corporate Body Established under Royal Charter do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to superconducting power supplies, and in particular to that kind of a superconducting power supply which operates on the transformer/rectifier principle for providing a direct current, from an alternating current input, for a superconducting circuit. For historical reasons superconducting power supplies are usually called and are hereinafter referred to as "flux pumps".

A known type of flux pump of the transformer/rectifier kind consists of a superconducting primary winding linked to two superconducting secondary windings which are connected in parallel and wound in opposite directions to one another. Switching means acting as rectifying means are incorporated sequentially to "switch-off" a secondary winding in phase with the frequency of the current in the primary winding, so that current is only permitted to flow in one direction in the secondary windings, thereby providing a d.c. output to the circuit.

It is usually desirable to make the windings of a flux pump from superconducting fine wires in order to reduce their a.c. losses. (even these fine wires are each composed of many hundred of fine filaments). In order to obtain an adequate current carrying capacity in the secondary windings it is necessary to connect many wires (in some instances of the order of 50) in parallel.

Problems arise when attempts are made to cycle the flux pump quickly, because this effectively means that the d.c. current flowing in the circuit must be rapidly switched from one secondary winding to another. Under these conditions the current in the circuit may not be shared uniformly between the parallel wires of a secondary winding, and for example, one wire will get too much current and "quench" (be driven from the superconducting to the resistive state) taking its neighbouring wires with it because of the heat it develops. Attempts have been made to overcome this problem by twisting, braiding or transposing the wires in the secondary winding, but they have only been partially successful.

It is therefore an aim of the invention to provide a flux pump in which the current is shared substantially uniformly by the wires of the secondary windings.

According to the present invention, a flux pump comprises a superconducting primary winding, two superconducting secondary windings which are connected in parallel but are wound in opposite directions, and switching means associated with each secondary winding arranged to switch off the winding sequentially in phase with the alternating current supply to the primary winding to provide a direct current output from the secondary windings, each secondary winding including a plurality of wires connected in parallel, wherein each wire in a secondary winding is connected individually in parallel with a corresponding wire in the other secondary winding to form a plurality of parallel circuits, and said switching means are adapted to be applied to each wire in the parallel circuits.

Preferably, the wires of each secondary winding are disposed in a cylindrical configuration and such that one winding is within the other, preferably about the outside surfaces of substantially concentric hollow right circular cylinders.

As used herein the term "superconducting wire" includes wires of circular and non-circular cross-section.

To enable the present invention to be more readily understood, attention is directed by way of example only to the drawings filed with the provisional specification wherein:

Figure 1 is a circuit diagram of a flux pump incorporating the invention in a superconducting circuit with a superconducting magnet.

Figure 2 is a diagrammatic representation of the disposition of the secondary windings, each having S_1, S_2... S_n wires, according to one form of the invention.

Referring now to Figure 1, a flux pump for providing a direct current Is in a superconducting circuit from an alternating current input Ip, comprises a primary winding P for inducing a current Is in a first and a second secondary winding wound in opposite directions to one another and connected in parallel. The first secondary winding comprises four wires S_1, S_2, S_3, S_4, and the second secondary winding comprises four wires S_1^1, S_2^1, S_3^1, S_4^1, the wires S_1 and S_1^1 being joined together to form a parallel circuit having a pair of wires wound in opposite directions to one another. Wires S_2 and S_2^1, S_3 and S_3^1, and S_4 and S_4^1, are similarly joined together to form a plurality of parallel circuits, all the said parallel circuits being in parallel connection with the superconducting circuit. A switching means of the thermal resistive type R_1, R_1^1, R_2, R_2^1, R_3, R_3^1, R_4, R_4^1, is provided for each of the wires S_1, S_1^1, S_2, S_2^1, S_3, S_3^1, S_4, S_4^1, respectively. A preferred form of switching means is disclosed in our co-pending patent application No. 36910/74, (Serial No. 1514486) in which a pulse of heat is applied to a length of superconducting wire at the commencement of the unwanted component of the alternating current in the wire to drive the said wire resistive from the superconducting state. Typically, a pulse length of 2 milliseconds may be applied for an alternating current of 50 cycles per second. A superconducting magnet 'M' is in circuit with the secondary windings.

In operation, the primary winding 'P' is energised by an alternating current Ip, and induces an alternating current Is_1, Is_2, Is_3, Is_4, in the wires S_1 S_1^1, S_2 S_2^1, S_3 S_3^1, S_4, S_4^1 of the secondary windings respectively. In known manner the resistive switches (rectifiers) R_1, R_2, R_3, R_4 and R_1^1, R_2^1, R_3^1, R_4^1, are synchronised with the frequency of the current Ip so as to "wipe out" the unwanted components of the induced alternating currents Is_1, Is_2, Is_3, Is_4, in each of the said wires of the secondary windings, and permit current to flow in one direction only. The current Is in the circuit simply alternates between individual pairs of wires S_1 S_1^1, etc. and does not have to redistribute itself between the four wires of each secondary winding in switching from one secondary winding to another. Although the invention has been described in relation to secondary windings having four superconducting wires, it is naturally applicable to any secondary winding of a flux pump having a plurality of superconducting wires. The invention has also been described in relation to thermal resistive switches which apply a pulse of heat to a superconducting wire, but other thermal resistive switching means, as well as non-thermal switching means such as magnetic switching means may be used.

Referring now to Figure 2, the wires of the first secondary winding S_1, S_2, S_3,... S_n, are shown spaced separately in a hollow cylindrical configuration, and wound at a constant helical angle. The said wires are formed into an inner cylindrical assembly 2 by winding them on a mandrel, bonding them together with epoxy resin and a layer of glass-cloth (not shown separately), and then removing the bonded inner assembly 2 from the mandrel, the helical angle of the wires being selected so that individual wires are on the same axial plane, at both ends of the inner assembly 2.

The inner assembly 2 is disposed within a similar, substantially concentric outer hollow, cylindrical assembly 4, of the same length as the inner assembly 2. The outer assembly 4 is formed from the wires of the second secondary windings S_1^1, S_2^1, S_3^1... S_n^1, similarly spaced separately and wound at a constant helical angle but with the helical angle in the opposite direction, with respect to the axes of the inner assembly 2 and outer assembly 4, to that of the first secondary winding. The outer assembly 4 is formed using epoxy resin and glass-cloth in the same manner as that described in relation to the forming of the inner assembly 2. For clarity only some of the wires of the first and second secondary windings have been shown in Figure 2.

The wires of a common output cable 6 are joined to the wires of the first and second secondary windings at both end faces of the assembly 2 at joints J_1, J_2, J_3... J_n to form a plurality of parallel circuits each having one wire in the outer assembly 4 and the other wire in the inner assembly 2. Electrical heating strips 8 and 10 wound around the inner assembly 2 and the outer assembly 4 respectively are arranged to heat all the wires of a secondary winding to drive them resistive. The primary winding (not shown) is wound around the second secondary winding in a substantially median angular inclination between the helical angles of the first and second secondary windings.

In operation, when a current is induced in the first and the second secondary windings by the primary winding, the heating strips 8 and 10 alternately heat the wires of the said secondary windings to

drive them sequentially resistive in synchronism with the frequency of the current in the primary winding, so as to "wipe out" the unwanted component of the induced alternating currents and permit a current to flow in the output cable 6 in one direction only.

WHAT WE CLAIM IS:—

1. A flux pump comprising a superconducting primary winding, two superconducting secondary windings which are connected in parallel but are wound in opposite directions, and switching means associated with each secondary winding arranged to switch off the winding sequentially in phase with the alternating current supply to the primary winding to provide a direct current output from the secondary windings, each secondary winding including a plurality of wires connected in parallel, wherein each wire in a secondary winding is connected individually in parallel with a corresponding wire in the other secondary winding whereby there is formed a plurality of parallel circuits, and said switching means are adapted to be applied to each wire in the parallel circuits.

2. A flux pump as claimed in claim 1, wherein the wires of each secondary winding are disposed in a cylindrical configuration and such that one winding is within the other.

3. A flux pump as claimed in claim 2, wherein the secondary windings are disposed in a helical manner but in opposite directions about the surfaces of substantially concentric cylinders, the helical angle being selected so that individual wires are on the same axial plane at both ends of the cylinders, and the primary winding is wound around the secondary windings at a substantially median angular inclination between the helical angles of the secondary windings.

4. A flux pump as claimed in any of claims 1 to 3 inclusive, wherein the switching means is adapted in operation to apply a pulse of heat to said each secondary winding at the commencement of the unwanted component of the alternating current in said each secondary winding to drive said each secondary winding to the nonsuperconducting state.

5. A flux pump substantially as hereinbefore described with reference to the drawings filed with the provisional specification.

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1 SHEET

FIG. 1.

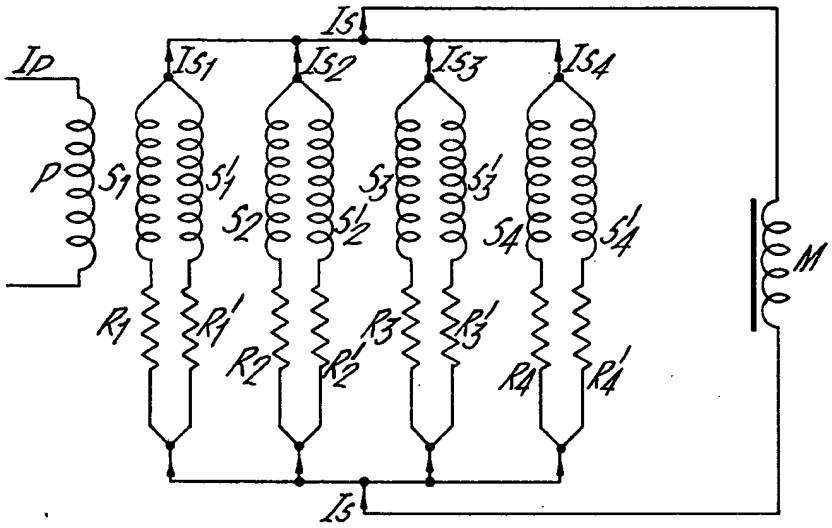

FIG. 2.